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Impact detection using a machine learning approach and experimental road roughness classification

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ABSTRACT

First, this publication presents the experimental validation of a road roughness classification method. Second, an impact detection strategy for two-wheeled vehicles is proposed including a classification of service loads, mild special events, and severe special events. The methods presented utilise the vehicle's onboard signals to gather field data. The modular road roughness classification system operates with the vehicle's transfer functions, and continuously classifies the road profile, according to ISO 8608. The method was successfully validated on test tracks with known road profiles. The impact detection strategy was developed using a supervised machine learning technique. Six road obstacles were ridden over using different velocities to invoke mild and severe special events. The most popular classifiers were trained for comparison and prediction of future observations. The developed impact detection strategy shows a high accuracy and was successfully validated using a k-fold cross-validation. The combination of the road roughness classification system and the impact detection strategy, enables a holistic field data acquisition of customer usage profiles, in the context of durability engineering. The collection of customer usage profiles improves vehicle design targets and enables a virtual load acquisition.

1. Introduction

The present publication combines a road roughness classification method with an impact detection strategy, in the context of durability engineering. Both methods are presented as an application for two-wheeled vehicles and were validated by experiments. The estimation and evaluation of the actual road roughness with the vehicle's onboard signals, has been the focus of many publications. The information about road roughness is often applied for active suspension systems or road surface maintenance. In the present research, the current road roughness is revealed and classified, to obtain a distribution of driven road classes, in the sense of field data collection. The underlying method of estimating the road roughness was developed by Gorges et al. [1] and is experimentally validated in the present publication. The modular road roughness classification system utilises the vehicle's transfer functions and classifies the road profile according to ISO 8608 [2]. A measurement campaign was carried out, which included rough, unpaved roads and obstacles for the experimental validation. The methods have been tested and validated with a real motorcycle ridden on test tracks, which were surveyed by a 3D roughness measurement system. The collection of driven road classes is part of gathering customer usage profiles, which improve vehicle design targets, especially in terms of lightweight design. Furthermore, customer usage profiles enable a virtual load

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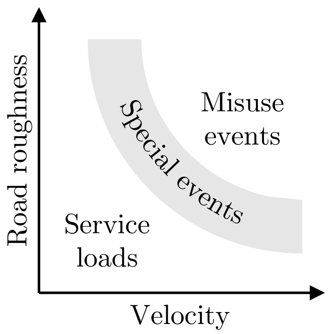
acquisition on virtual test tracks. Thus, the knowledge about driven road classes is an improvement in the product development.

In the context of durability, the combination of customer behaviour and road roughness indicates whether the loads that occur are considered as service loads, special events, or even misuse events, as Fig. 1 shows. According to the authors, an increase in the vehicle velocity induces higher loads for a given road roughness, and vice versa, see Fig. 1a. Especially in the automotive industry, and referring to Matz [3] and Pötter [4], customer loads are divided in three categories: service loads, special events, and misuse events, as shown in Fig. 1b. On the one hand, this separation is characterised by statistical considerations. On the other hand, this distinction is necessary for product liability and warranty. For example, an off-road motorcycle is designed for unpaved roads and even small jumps, which means, up to a specific threshold, the impacts of these events are regarded as service loads. While for a superbike, the manoeuvres described would be regarded as special events or misuse events. Johannesson and Speckert [5] described the customer load distribution "in terms of vehicle-independent load environment together with the vehicle usage and the vehicle dynamics". This description coincides with the presented derivation of customer loads.

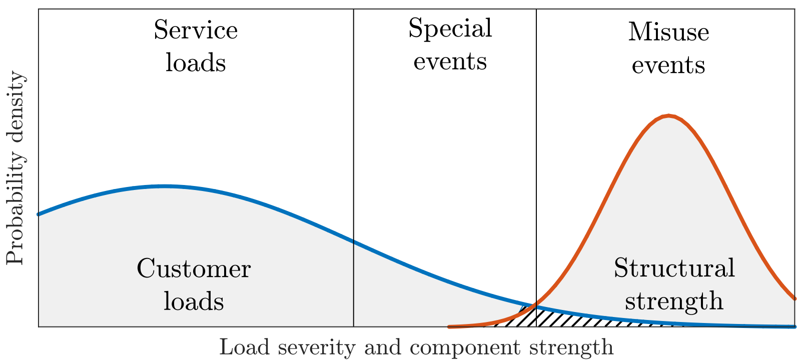
Service loads occur during the normal use of the vehicle, which is often called the intended purpose. They can be described by a continuously distributed load spectra during the life of the vehicle. In the case of a motorcycle, service loads comprise acceleration and brake manoeuvres, cornering, and loads that occur due to the roughness of the road surface. In addition to the service loads, the intended purpose also includes the occurrence of special events. Special events are rare compared to service loads, and they induce a higher load on the vehicle components. They are often characterised by impacts from sudden events, for example, driving over a pothole. As special events are part of the intended use of the vehicle, the components must be designed to sustain the loads. After the occurrence of a special event, the vehicle still has to be fully operational.

Misuse events are per definition not part of the intended purpose, but they are also considered during the vehicle design process. In engineering, the fail-safe principle is applied, which means that the components should deform plastically along the load path. This is called the damage chain. Fig. 1b shows that in misuse events, the load severity typically coincides with the structural strength of the components. The customer should be able to clearly identify the damaged structure, and recognise that the components were over-exposed in consequence of the misuse event. Misuse events are characterised by a higher load level that exceeds a defined threshold, and are also often the consequence of impacts, for example riding against, or over a significant obstacle. The load threshold between special events and misuse events, is often determined by numerical simulation and validated with experiments. Further aspects of misuse, in the context of structural durability, have been discussed by Köhler et al. [6], Hauke [7], and Berger et al. [8]. The methods presented can be categorised as condition monitoring systems. For two-wheeled vehicles, the publication of Gorges et al. [9] shows a real-time, wheel force calculation, with subsequent rainflow counting, to derive customer loads. An example for passenger cars can be found in Matz [3].

The road roughness classification method presented, is designed for a continuous evaluation of the driven road classes. Due to the restrictions of the underlying full-vehicle model, the method works under normal operation conditions, which means service loads. The system is not intended for the detection of single events, for example passing over obstacles, nor for the evaluation of the loads that occur. For this reason, the second part of the present study investigates the development of an impact detection strategy. Since the threshold between service loads, special events, and misuse events is, not defined by specific loads and strains, a machine learning approach was evaluated. Different road obstacles were ridden over, at different velocities, to gather an adequate data set of labelled observations. Subsequently, various supervised machine learning techniques, in form of classification, were evaluated. It is called supervised machine learning, because the data set was labelled before the classifier was trained. Knowledge about the distribution of special events during the product's life, is highly valuable for improving vehicle design targets.



(a) as a combination of road roughness and vehicle velocity



(b) as a probability distribution

Fig. 1. Classification of customer loads.